the soutwest. That is in conformity with the topography and the low-level divergence of the monsoon current over southwest Pakistan.

To describe the summer rainfall climate of Afghanistan by using only the arithmetic mean values has certain disadvantages as the precipitation normally falls in isolated showers. In the Hindu Kush mountains for instance, years can elapse between individual showers. The median values of rainfall have therefore been calculated as well. In comparing the mean values with the median values the following definitions have been introduced:

1. When the mean and the median values show the same secondary summer maximum, the station is considered to be regularly influenced by monsoon precipitation.
2. When there is a secondary summer maximum in the mean value, but not in the median value, the station is considered to be only occasionally influenced by monsoon precipitation.

The boundaries between regularly and occasionally influenced areas are illustrated in Fig. 13. These areas are of course not necessarily identical with the areas occupied by monsoon air. Some years Jalalabad, for instance, does not receive any rain at all during the monsoon months, although humidity records clearly indicate that maritime airmasses normally reach the station at the beginning of June and remain there until the middle of September (Fig. 14). One reason is obviously that Jalalabad is situated in the rain shadow of the monsoon current. Therefore, although the elevation of Jalalabad is about 220 m higher than that of Peshawar its precipitation is only 10 % of that at Peshawar.

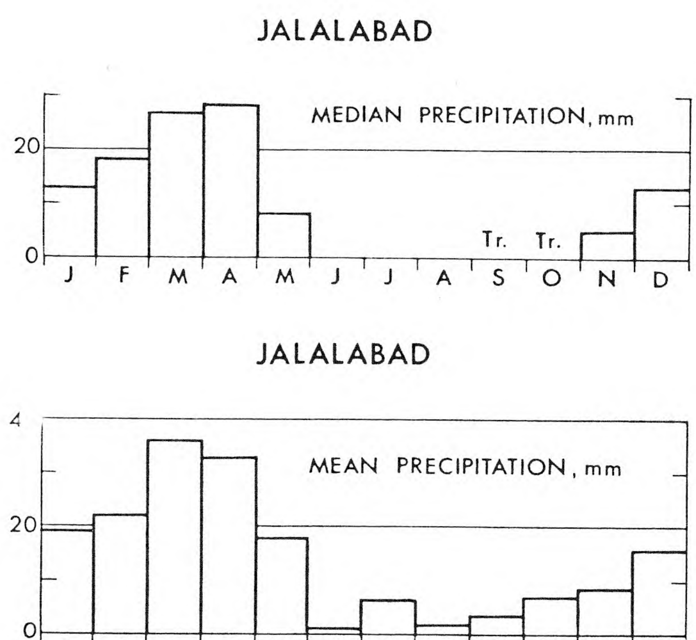


Fig. 14. Monthly means and median values of rainfall in Jalalabad. The secondary maximum of the mean value in July does not appear in the median value for that month. Jalalabad is therefore considered to be only occasionally influenced by monsoon rainfall.

Synoptic features of the Summer Monsoon

In dealing with the synoptic aspects of the monsoon circulation over eastern Afghanistan the author has been bound by some restrictions in time and space:

1. As upper air observations are available mainly from Kabul and Peshawar, and for a few months in 1965 also from Jalalabad, the main synoptic interest has been concentrated to the northeastern parts of the country.
2. Situations selected for more detailed studies have been restricted to periods when simultaneous upper-air data from two or three of these stations have been available.
3. Irregular pibal data from Mazari Sharif and Kandahar, as well as irregular radiosonde/wind data from Quetta have been used, but only if they coincide in time with the upper air data from Kabul and Peshawar.

Although the topography is of basic importance for the precipitation in Afghanistan, rain is rare, when the monsoon circulation is undisturbed. Widespread showers/thunderstorms are normally produced only by convergence associated with monsoon depressions arriving from E or SE. Thus the monsoon circulation must be well established before the first depression of the season can arrive in the country. Although the time for the first summer shower is a climatological factor of interest, its synoptic significance is less obvious. The stratification of the airmasses involved in the circulation seems to be even more important than the characteristics of the airmasses themselves.

The *burst of the monsoon* is characterized by a series of events taking place during a period that differs from place to place. Its duration can also vary somewhat from year to year. How-

ever, it principally involves the following two phases:

1. *Advance of the monsoon* or the building up of the monsoon circulation normally from mid-May to the beginning of June.
2. *Peak of the monsoon* from the arrival of the first monsoon depression, normally during the first weeks of June, and up to the last showers in August or the beginning of September.

Whereas in India and Pakistan it is possible —in most cases—to make a clear distinction between these two phases, it is not so in Afghanistan, as this country is situated on the periphery of the area affected by the monsoon. The *advance of the monsoon* is not to be understood as a steady motion of the ITF west and northwards, nor is the *peak of the monsoon* a stationary state. Both phases are buoyant, and the ITF is subject to oscillations. Irregular impulses related to variations in the stream field are superimposed upon regular impulses related to diurnal variations of pressure and wind. The large-scale orographic influence of the Hindu Kush and the mountains along the Afghan-Pakistan border complicates the circulation further.

During the pre-monsoon period the continental air is normally cooler than the maritime air. Along the ITF the continental air thus must be situated *below* the maritime air. The westwards penetration of the maritime air over Afghanistan during the advance of the monsoon can therefore be expected to take place at higher levels (see the cross section Kabul-Jalalabad in Fig. 15). Over Kabul the upper easterly flow is about 1000 m thick, and it is overlain by a northwesterly flow. Examining the Kabul lapse rate we find in the layer between 6000 and 7000 m a temperature gradient that is lower than at any other level. This fact, together with the marked decrease in the humidity above 6000 m seems to indicate that we are dealing with continental air. The layer between 6000 and 7000 m is thus a mixing layer separating the antimonsoon from the upper planetary northwesterly flow of continental air. The monsoon circulation is in other words embedded in the continental air over Kabul. With this interpretation in mind it seems fair to assume, that the first showers of the season as reported in Kabul and Karizimir on June 8th (Table 2) can be attributed to the injection of maritime air aloft. However, no showers were reported in Jabul Saraj and Salang, situated a further 50—70 km north of Kabul. It is therefore unlikely that the upper monsoon circulation had reached these places.

In 1966 the first monsoon showers of the season were reported in Kabul and Karizimir

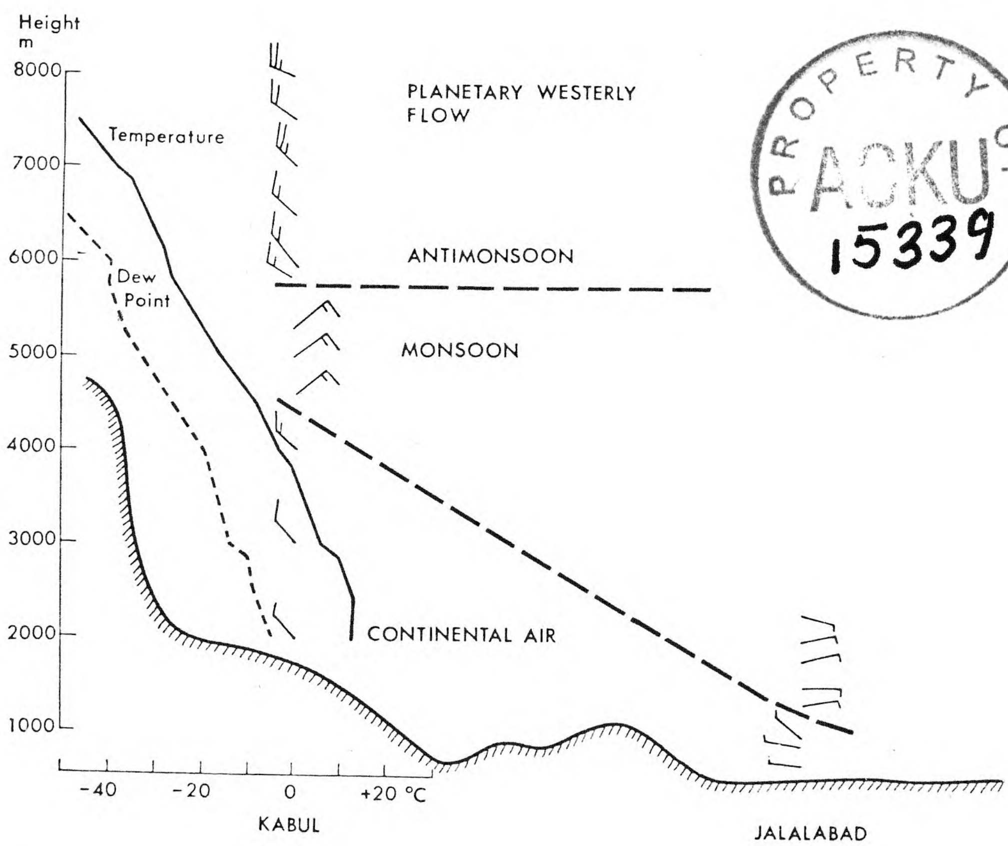


Fig. 15. Pre-monsoon circulation between Kabul and Jalalabad on 6 June 1965. The monsoon air is warmer than the continental air, and its westward penetration therefore takes places above the continental air.

Table 2. Date of the first monsoon shower at some Afghan stations. When there are gaps in the records no date is given. Only Jalalabad, Ghazni, Kabul and Karizimir have been in operation the whole period 1960—1971.

Station	Year											
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Khost	—	—	11.6	17.6	4.6	4.6	1.7	13.6	1.6	7.6	8.6	7.6
Jalalabad	20.6	7.6	12.6	1.6	2.6	3.7	—	15.6	—	14.7	12.6	14.6
Ghardez	—	—	—	—	13.6	1.6	1.6	15.6	8.6	2.6	3.7	1.6
Ghazni	19.6	18.6	30.6	—	9.6	13.6	1.6	2.6	13.7	9.6	27.6	7.6
Lagman	—	—	—	—	—	4.6	1.6	2.6	1.6	18.6	5.6	7.6
Kabul	1.6	8.6	5.6	2.6	5.6	8.6	2.7	1.6	1.6	1'6	5.7	21.6
Karizimir	21.6	7.6	11.6	1.6	10.6	8.6	8.7	2.6	1.6	1.6	14.6	7.6
Jabul Saraj	—	7.6	7.6	—	18.7	2.7	15.7	15.6	3.6	9.6	14.6	—

at the beginning of July, i.e. considerably later than normal. Conditions over Kabul on June 6th that year as illustrated in Fig. 16 can serve as an example for the whole month of June 1966. There were westerly winds up to at least 12000 m. The upper monsoon circulation had thus not reached Kabul and no showers could be expected.

The advance of the monsoon also involves a gradual change of the thermal properties of the tropospheric airmasses taking part in the circulation. During that period the continental air is gradually converted from a cold to a warm mass due to increased insolation in the source region, whereas the maritime air is cooled by the rainfall further east. It follows, that the thermal differences must first vanish, then increase, but in the opposite direction.

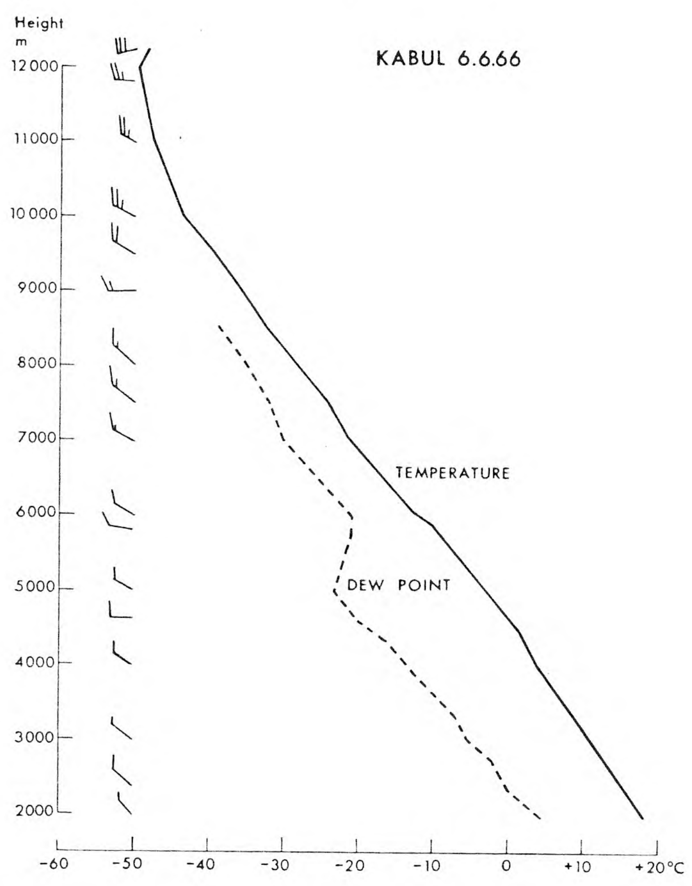


Fig. 16. Conditions over Kabul on 6 June 1966. The upper monsoon circulation has not reached Kabul (compare Fig. 15).

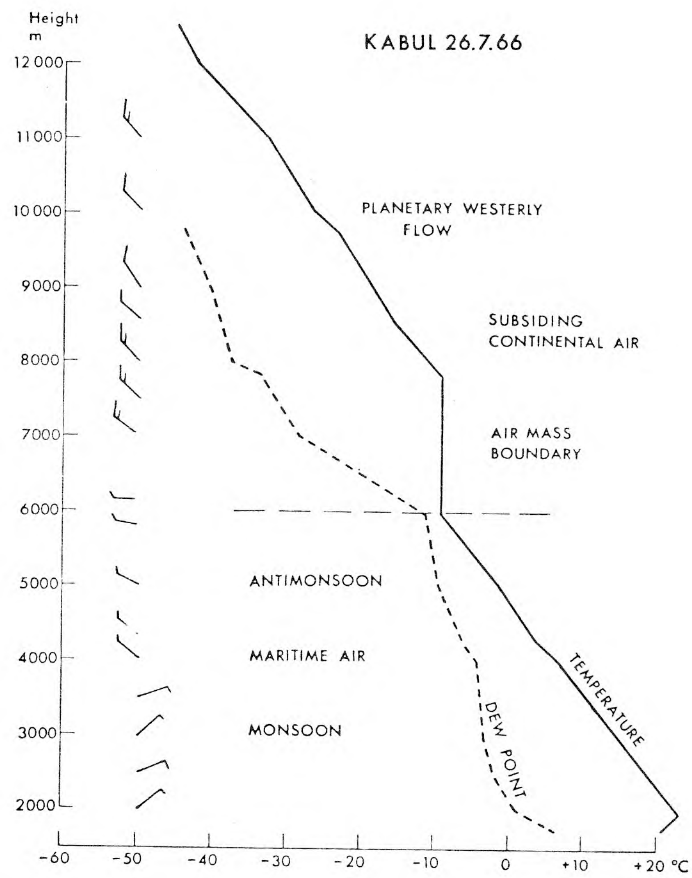


Fig. 17. Conditions over Kabul on 26 July 1965 with the monsoon circulation well developed. The isothermal layer above 6000 m is an airmass boundary separating the lower humid and rather cool monsoon air from the upper dry and potentially warmer continental air.

That means, that towards the peak of the monsoon the cooler maritime air will be situated below the warmer continental air. Principally the advance of the monsoon is thus synchronized with a change of the airmass stratification in the lower troposphere. There are, however, exceptions from this general rule due to deviations from the normal conditions in the airmass source regions.

During the peak of the monsoon the ITF can sometimes be situated west of Kabul, and such an example is illustrated in Fig. 17. The northeasterly flow up to 3500 m (1700 m above ground) is the monsoon current of maritime air, now somewhat cooler than the continental air. The antimonsoon is well marked in the windshift as well as in the high values of humidity. The isothermal layer on top of the antimonsoon is a more or less permanent feature throughout the peak of the monsoon, and for the weather it is of basic importance. The convection below the isothermal layer is in most cases strong, but only occasionally does it break through the isothermal layer. The thickness of the moist layer as represented by the monsoon circulation is in this example 6000 m, i.e. somewhat more than reported by Pisharoty (1963) in India north of 15° N.

The isothermal layer separates the lower cool maritime air from the upper relatively warm continental air. *It thus represents an airmass boundary,* although most likely subsidence due to anticyclonic foehn also might contribute to the formation and preservation of the layer. But the primary reason for the reverse horisontal temperature gradient in the north-south direction over the northern part of L_2 is no doubt the thermal contrasts between the continental and the maritime airmasses as pointed out by Desai.

We are now in the position to make a summary of our findings and compare the circulation over eastern Afghanistan with that over northern India and Pakistan as presented by Sawyer (1947). During the pre-monsoon period, when the continental air is cooler than the maritime air, the monsoon circulation affects eastern Afghanistan only in higher levels, and only there a significant temperature difference between the airmasses can be observed. At lower levels and at the surface the temperature contrasts are small. We arrive at a principal circulation model for the area between Kabul and the Pakistan border as illustrated in Fig. 18. The weather in Kabul at this stage is normally clear occasionally with some flat cumulus humilis.

Earlier has been pointed out, that towards the peak of the monsoon, the continental air becomes relatively warmer than the maritime air. Sawyer has stressed, that the lapse rate of the continental air at this stage is steeper than that of the maritime air. Above a certain height the temperature differences between the two airmasses will therefore be different from that at lower levels. The maritime air will again be warmer than the continental air, and consequently be situated above the continental air. The westwards penetration of the maritime air towards the peak of the monsoon is most pronounced at lower levels, and a change of the airmass stratification will therefore affect only those levels. At higher levels the stratification will remain unchanged, but the temperature and humidity contrasts will in most cases

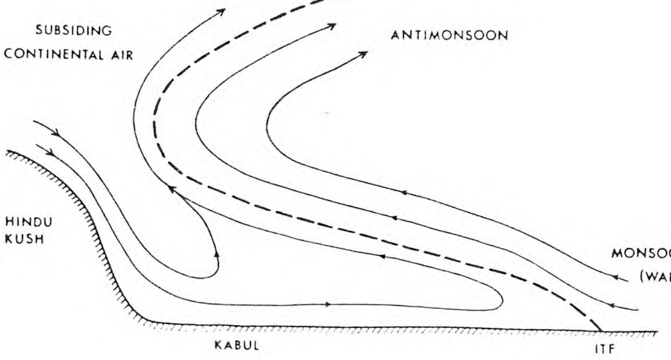


Fig. 18. Principle pre-monsoon circulation over eastern Afghanistan.

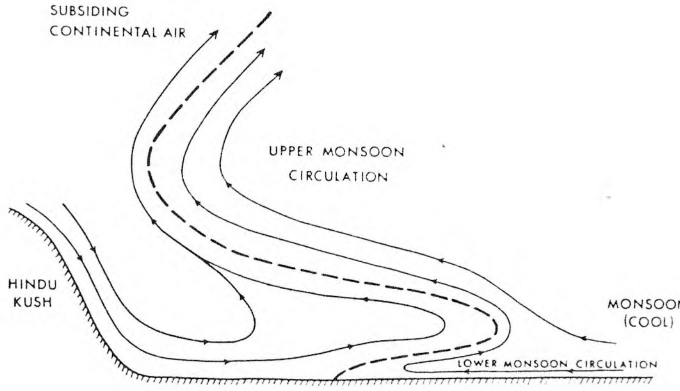


Fig. 19. Principle monsoon circulation over eastern Afghanistan during the peak of the monsoon. Notice the lower monsoon circulation to the east overlain by the main monsoon circulation.

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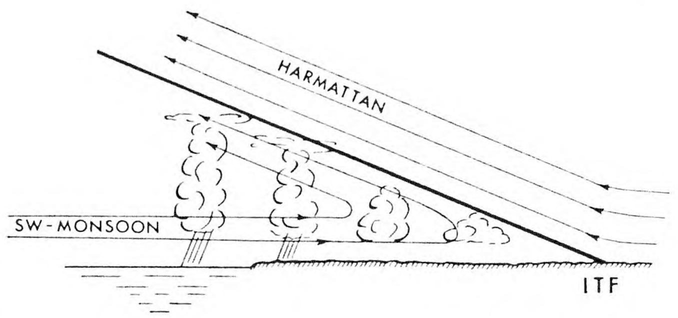


Fig. 20. Monsoon circulation over West Africa. The moist SW-monsoon is overlain by the dry Harmattan (compare the lower monsoon circulation in Fig. 19).

be more pronounced because of intensified convection in the maritime air, and probably a more intensified anticyclonic subsidence of the upper continental air. We arrive at a model basically including two monsoon circulations; one low-level monsoon circulation overridden by the main monsoon circulation as illustrated principally in Fig. 19.

From 25 pibal observations made in Jalalabad, about 140 km east of Kabul, during the months June—August 1965, the average thickness of the lower easterly monsoon current has been found to be about 1200 m, and the top of the lower antimonsoon current about 2000 m. Conditions are in some respects similar to those in West Africa, where the humid SW-monsoon is overlain by the dry Harmattan as illustrated in Fig. 20. In case of undisturbed circulation, rainproducing cold clouds cannot form close to the surface ITF. Instead the main precipitation falls some hundreds of km south of the ITF. Conditions in eastern Afghanistan are somewhat more complicated than in West Africa due to the presence of high mountain ranges, which

1. deflect the already deflected monsoon current from SE to E or NE,
2. create a deviation from the *normal* distribution of rainfall. With *normal* is here meant an annual distribution similar to that found in West Africa.

A circulation model taking into account not only the Hindu Kush mountains, but also the mountain range along the Afghan-Pakistan border between Jalalabad and Peshawar is presented in Fig. 21. Of particular interest is the lower monsoon circulation, which seems to have been split up into two separate cells because of the mountain range between Jalalabad and Peshawar.

As has been seen earlier in this study (Fig. 2), the average position of the ITF in July is between Kabul and Jalalabad, viz. in the neighbourhood of Laghman, situated about 50 km east of Kabul. Kabul has in that situation sometimes cloudy weather, and occasionally also thundershowers. Most significant, however, are the duststorms, which are frequent in the afternoon, when strong isallobaric winds are created by the diurnal deepening of the low centre to the east. Jalalabad is on the *wet side*

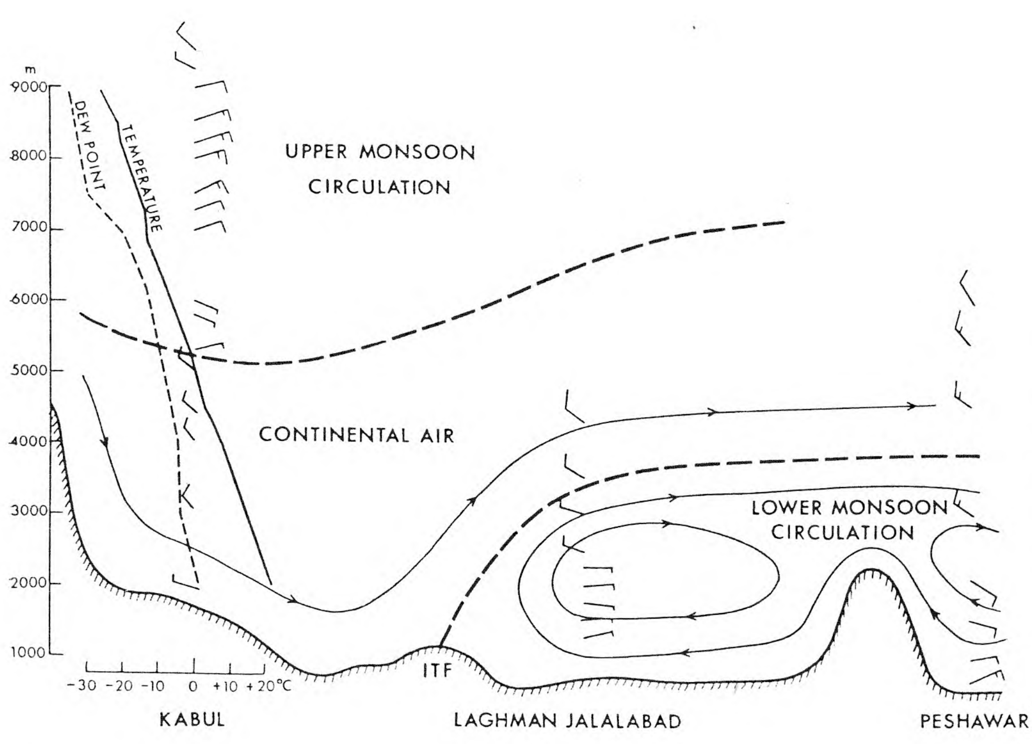


Fig. 21. Actual monsoon circulation between Kabul and Peshawar during the peak of the monsoon (8 August 1965). The ITF is situated in the neighbourhood of Laghman. The moist layer over Jalalabad is too shallow to permit convective cloud formation. The lower monsoon circulation is split up into two cells due to the mountain range along the Afghan-Pakistan border.

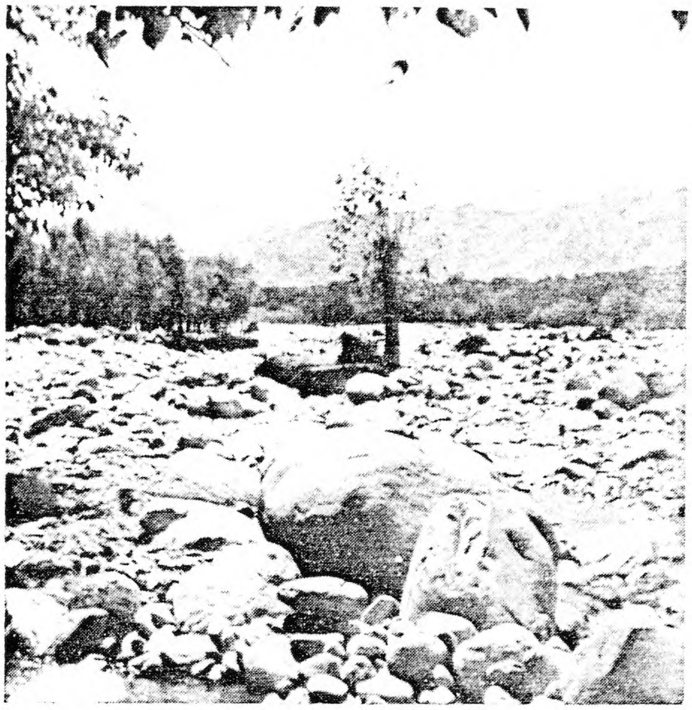


Fig. 22. Remains of gardens outside the Nejrab village spoiled by floods on 15 July 1970. The village is situated between Jabul Saraj and Jalalabad, about 50 km NW of Jalalabad.

of the ITF, but the moist layer is too shallow to permit formation of any rain-producing clouds. The weather is *sultry,* but normally clear with a grey sky.

Although no reliable statistics exist, it is well known that the monsoon showers, which occur every year, sometimes lead to devastating floods in many parts of northeastern Afghanistan. SELAU is a common name of the phenomenon. The expression can be derived from the Farsi word SEL = flood, and AU = water. Thus SELAU basically means more the effects of the showers rather than the meteorological phenomenon itself (Fig. 22).

A question of main interest is the ultimate limit of the monsoon air penetration into the Kabul valley. Occasionally it no doubt fills most of the valley north and northwest of Kabul, but it rarely reaches Jabul Saraj. That place is situated at a point where the valley becomes very narrow, and where it slopes steeply up to the Salang pass—the highest point on the highway northwards from Kabul. Conditions are consequently favourable for the continental air to blow as katabatic winds from the tops of the Hindu Kush, which are snow-covered even in summertime, down into the valley at Jabul Saraj. Because of the narrowness of the valley the wind is forced through it, resulting in a funnel effect with frequent excessively strong winds. It is therefore fair to assume that the monsoon air cannot reach Jabul Saraj at lower levels. The Hindu Kush seems to form an effective barrier.

On the slope of the mountain a few kilometers to the south of Jabul Saraj a natural phenomenon is observed which at a first glance seems to contradict the above statement (Fig. 23). Alexander Burnes (1840), who visited the place already in 1836, describes it as follows: "We are now in the vicinity of Reg-Ruwan or the moving sand . . . Between the plains there

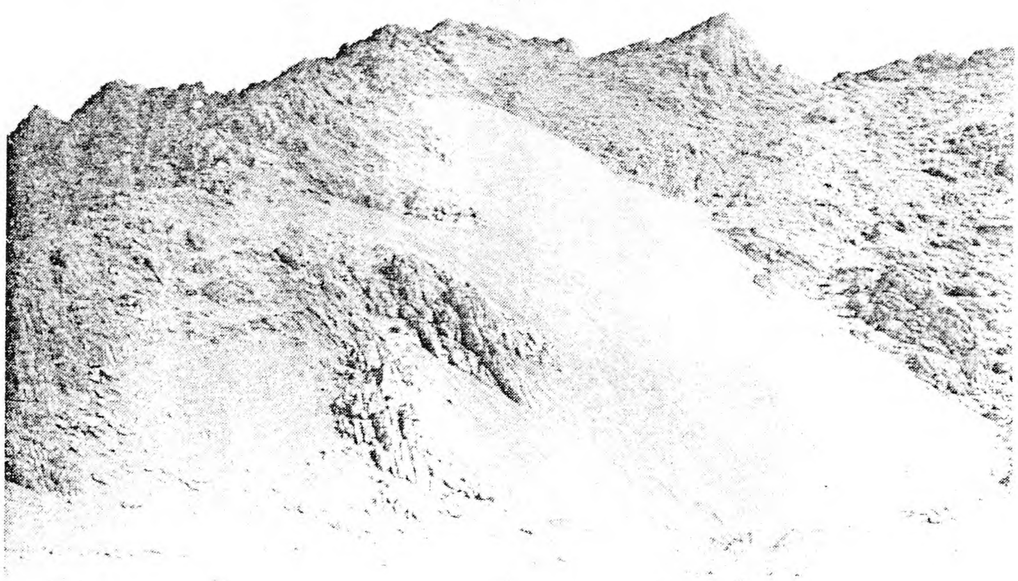


Fig. 23. The sand deposit of Rag-Ruwan seen from the South at a distance of about 2 km.

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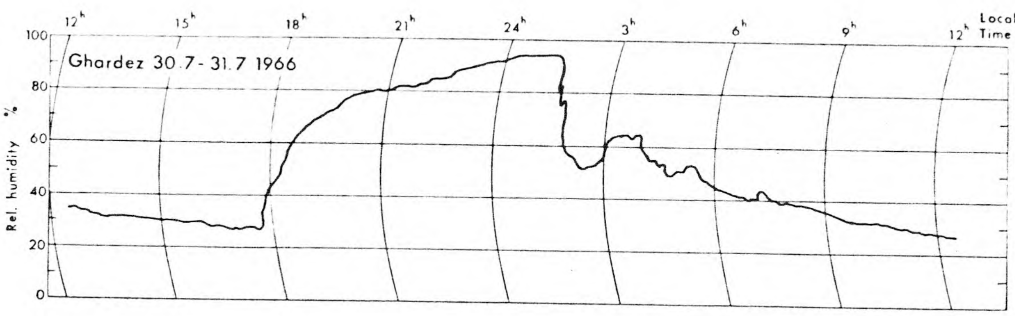


Fig. 24 a. Hygrogram from Ghardez 30—31 July 1966. The sudden increase in humidity at 1745 indicates the passage of the ITF.

is a small hill, in which there is a line of sandy ground, reaching from the top to the bottom . . . Reg-Ruwan faces the south, but the wind of Purwan (name of the province), which blows strongly from north for greater part of the year probably deposits it by an eddy. Such is the violence of this wind, that all trees in the neighbourhood bend to the south, and the fields after a few years require to be re-cleared of the pebbles and stones, which the loss of soil lays bare."

The sand deposit of Reg-Ruwan is the result of a very permanent southerly air current, which, however, has no direct connection with the monsoon circulation. As suspected by Burnes, it is no doubt a lee-eddy phenomenon in the northerly katabatic flow, similar to that illustrated in Fig. 3 b.

Conditions in higher levels are less clear due to lack of upper air data west and north of Kabul. However, Jabul Saraj as well as the stations on the top of the Salang pass, and some of those situated further west have secondary summer maxima in the mean rainfall. This seems to indicate that cooler monsoon air can be injected into higher levels over the Hindu Kush, thereby creating conditionally unstable conditions.

Monsoon pulses

The pulsating character of the monsoon current is reflected in periodic as well as non-periodic movements of the ITF. The phenomenon appears not only at the surface, but also in higher levels.

On the mean pressure chart for July in Fig. 2, the average position of the ITF is over Ghardez. One can therefore expect that during the peak of the monsoon the ITF will oscillate around that place. For a more detailed study of the movements of the ITF we will therefore examine available hygrograms not only for Ghardez, but also for Khost, situated 65 km east of Ghardez, and for Ghazni, situated 65 km west of Ghardez.

The hygrogram in Fig. 24 a is significant for Ghardez. The ITF seems to have passed over the station at 1745 local time, when there was a sudden increase in the humidity. At 0130 there was an equally sudden decrease, indicating the retreat of the ITF.

Khost is normally on the *wet side* of the ITF throughout the peak of the monsoon. However, on July 31, 1966 (Fig. 24 b) Khost seems to have been situated on the *dry side* up to 1640, when the ITF passed. At 2000 the same evening the ITF passed Ghardez (Fig. 24 c). The speed of the ITF was in this case about 20 km/h. At 2345 it seems to have passed over Ghardez again, but on the way eastwards, and finally it passed over Ghardez for a third time at 0145. The oscillation of the ITF around Ghardez seems in this case to be well verified. This method has been used in an examination of all hygrograms for August 1968, and for

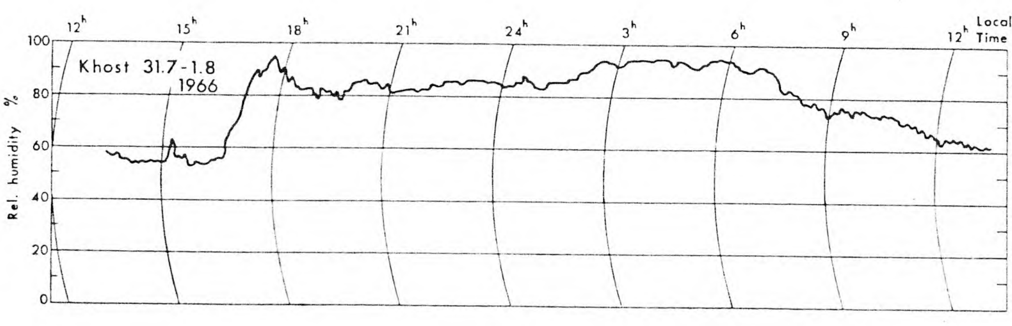
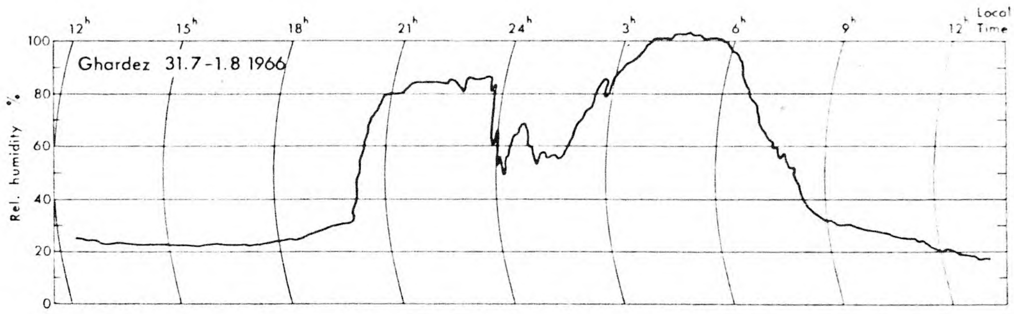


Fig. 24 b. Hygrogram from Khost 31 July—1 August 1966. The ITF seems to have passed at 1640 (compare Fig. 24 a).

Fig. 24 c. Hygrogram from Ghardez 31 July—1 August 1966, illustrating the oscillation of the ITF through that station. The ITF seems to have passed the station at 2000 and 2345 on 31 July, and at 0145 on 1 August (compare Fig. 24 a and b).



July and August 1970. The result is given in Table 3.

The oscillation of the ITF in horisontal direction is well known particularly from Africa. It was for instance studied in Sudan by Solot (US Airforce 1943) and in Tchad by Neviere (1959). In most cases the displacement of the ITF seems to be a result of the diurnal variation of pressure. As to the amplitude of the displacement, there is in Table 3 only one case —on July 20, 1970—when the ITF passed over Khost, Ghardez and Ghazni on the same day.

Table 3. Amplitude and speed of the ITF oscillations calculated from the time of passing over Ghazni, Ghardez and Khost. During the peak of the monsoon (July—August) the ITF seems to oscillate through Ghardez. Khost, situated about 65 km east of Ghardez, is normally on the "wet side", and in August it is not affected by the ITF.

	July 1970				August 1968			August 1970		
Date	Ghazni	Ghardez	Khost	Speed	Ghazni	Ghardez	Speed	Ghazni	Ghardez	Speed
1	—	—	—	—	—	1740	—	—	1845	—
2	—	1620	—	—	—	1915	—	2030	1710	20 km/h
3	—	—	—	—	—	1900	—	1935	1615	20
4	—	1630	—	—	—	1520	—	—	1845	—
5	2030	1530	—	13 km/h	—	1635	—	—	1930	—
6	1930	—	—	—	2045	1705	18 km/h	—	1930	—
7	—	—	—	—	2140	1740	16	—	1715	—
8	—	2045	—	—	—	1910	—	—	1620	—
9	—	—	—	—	—	1840	—	—	1630	—
10	—	1940	—	—	2135	1725	16	1920	1715	30
11	—	1950	—	—	2030	1550	15	1930	1615	20
12	—	—	—	—	2045	1700	17	1920	1700	27
13	—	1945	1620	20	2340	—	—	1950	—	—
14	—	1840	—	—	—	1730	—	1940	1700	25
15	—	1935	—	—	—	1850	—	1835	—	—
16	2315	1810	—	13	2215	1840	17	2050	—	—
17	2010	1515	—	13	2245	1815	15	1940	1625	20
18	2035	—	—	—	2215	1650	12	—	—	—
19	—	1900	—	—	—	1845	—	—	—	—
20	2200	1835	1655	25	—	1815	—	—	—	—
21	2010	1615	—	16	—	1700	—	—	—	—
22	—	—	—	—	—	—	—	1840	—	—
23	—	1945	—	—	—	1900	—	—	—	—
24	2115	1715	—	16	—	1945	—	—	1845	—
25	—	—	—	—	—	1640	—	—	1730	—
26	—	1815	—	—	—	1910	—	2000	—	—
27	1900	—	—	—	—	—	—	—	1750	—
28	1930	—	—	—	—	1830	—	—	1740	—
29	2210	1700	—	12	—	1930	—	—	1845	—
30	2115	1820	—	22	2015	1730	23	—	1830	—
31	—	1820	—	—	—	1835	—	1735	—	—

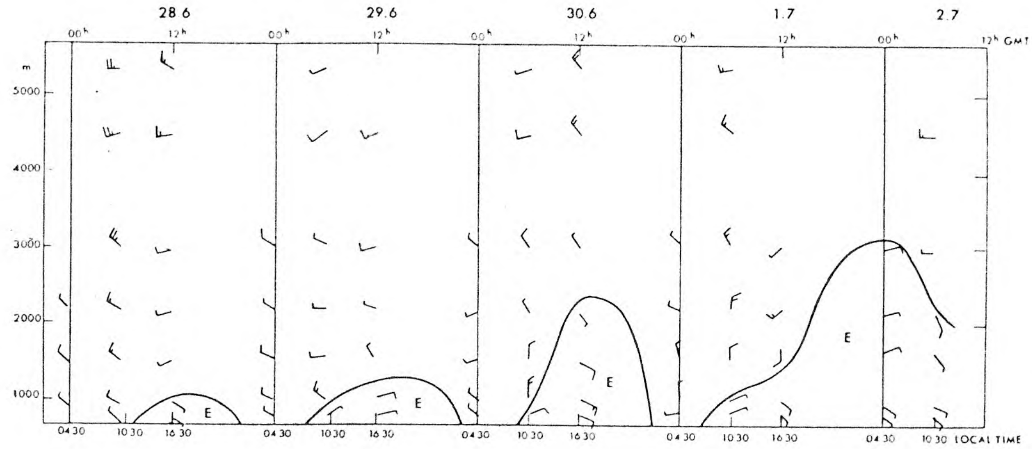


Fig. 25. Pulsating character of the easterly monsoon current penetrating Peshawar 28 June —2 July 1965.

The amplitude was in that case consequently about 130 km, i.e. close to the value given by Powell and Pedgley (1969) in Niger. In all other cases investigated the amplitude is less, and of the same order as reported by Weston (1972) in northeast India.

The pulsating character of the monsoon current in the upper atmosphere is illustrated in the example from Peshawar (Fig. 25). On June 28, 1965, the easterly monsoon current affected Peshawar only in the lowest 1000 m, and at 1630 local time. Next day also the 1030 observation showed a shallow easterly current. On the evening of June 30th the thickness had increased to more than 2000 m. On July 2nd finally, the 0430 observation also showed an easterly component, and the monsoon current dominated all levels up to 3000 m.

Fig. 26 illustrates the condition over Jalalabad a few days later. Also here the pulsating character of the monsoon current can be recognized, as well as the gradual replacement at the surface of the continental air by cooler maritime air. That process was in the example completed on July 10th.

Monsoon breaks

A break in the monsoon can principally be referred to one of the following reasons:

1. Cut off in the supply of maritime air. That can happen at any time during the monsoon season. Synoptically it means either a gradual retreat eastwards of the ITF, or simply a fading away of the monsoon circulation.
2. Change of the airmass stratification as a result of deviations from the normal airmass properties of the season. That is obviously most likely to take place at the beginning or towards the end of the monsoon season. Such deviations generally occur in connection with the passage of a westerly wave disturbance, which, however, in most cases is weak and without any significant weather manifestations.

An example of such a westerly wave disturbance during the monsoon season is given in Fig. 27 a—d. The 500 mb streamline charts show a well marked trough passing across northern Afghanistan during the period 28—31 July 1966. Table 4 gives the weather in Kabul during the period 29 July—4 August, and Fig.

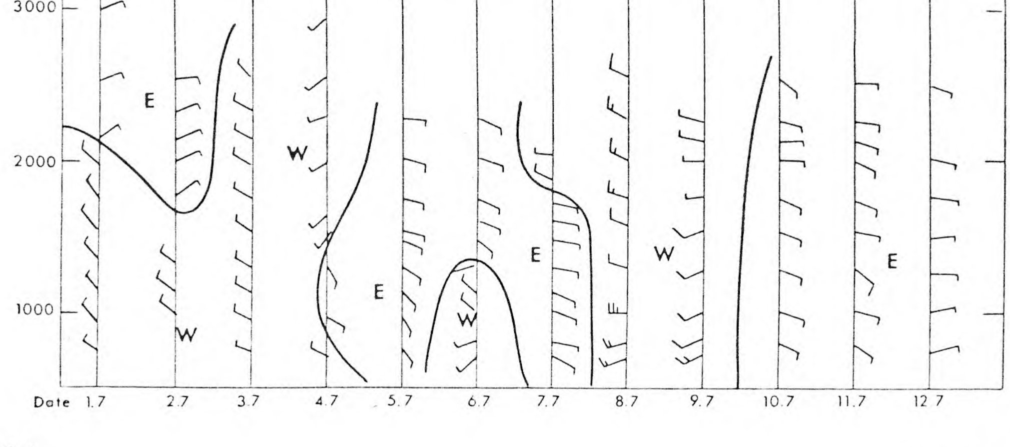
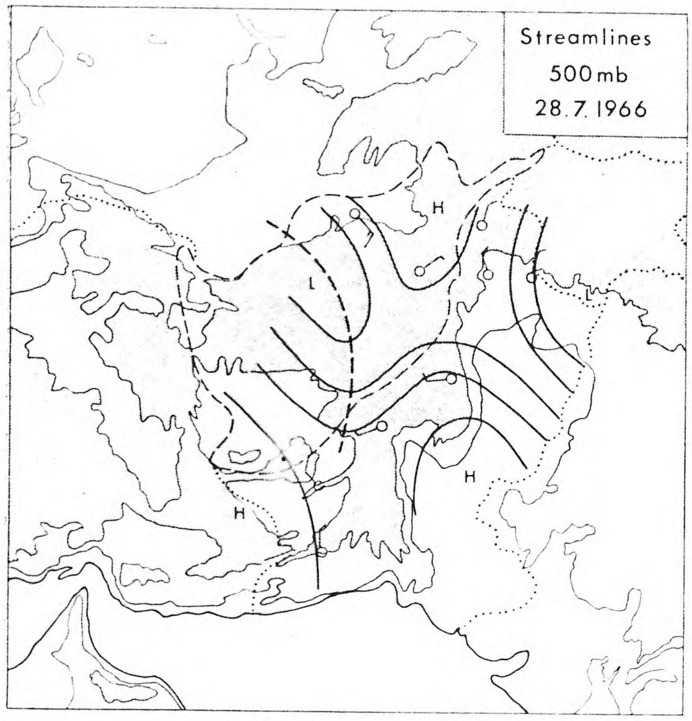


Fig. 26. Pulsating character of the easterly monsoon current penetrating Jalalabad 1—12 July 1965.



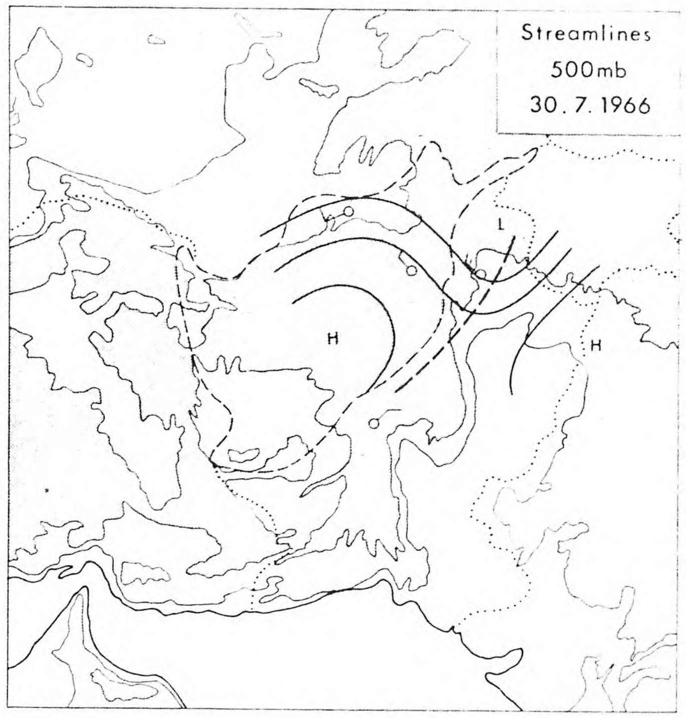
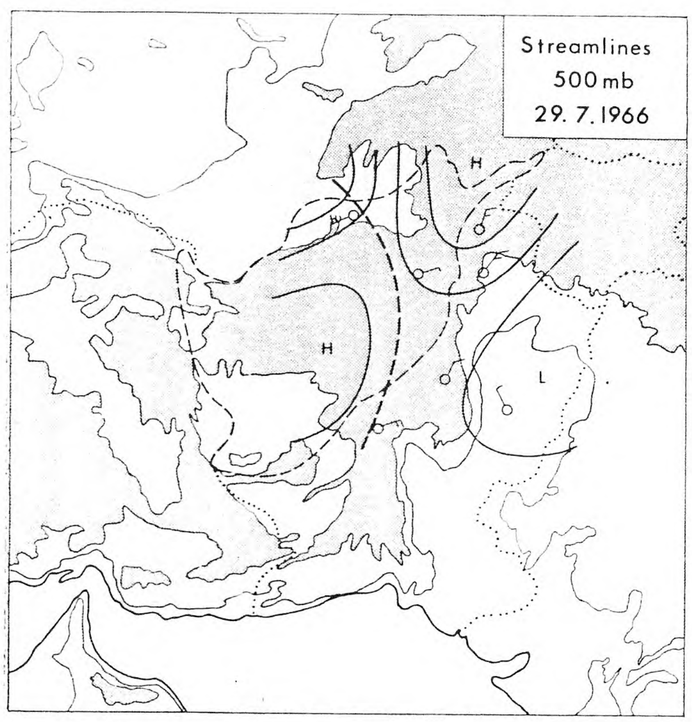
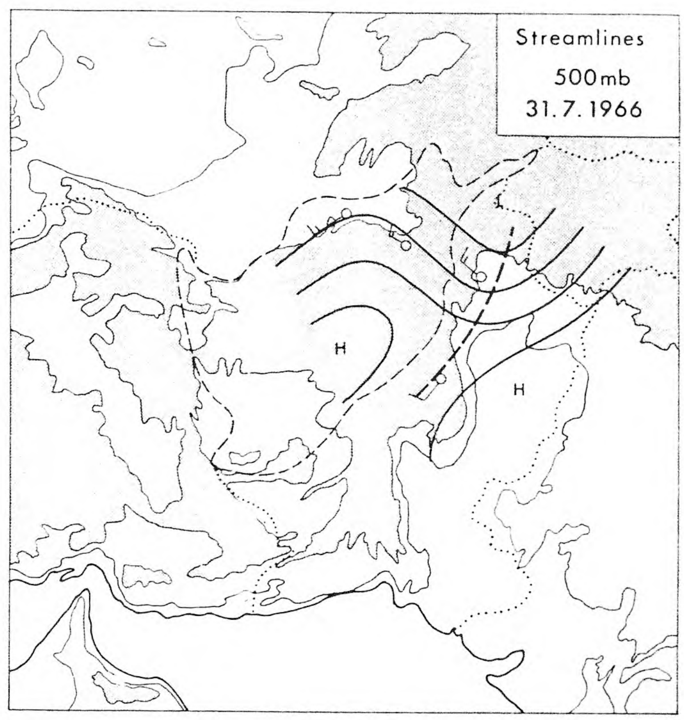


Fig. 27 a—d. 500 mb streamline charts illustrating a weak westerly wave disturbance passing across northern Afghanistan during the peak of the monsoon (28—31 July 1966).





28 illustrates the upper air conditions over Kabul during the same period.

At the surface the trough passed over Kabul on 30 July between 0900 and 1200 GMT (1330 and 1630 local time), when there was a sudden and well marked increase of the dew point depression. The wave was high-reaching and had a marked wind shift. The greatest temperature difference was found at the 600—650 mb level, the continental air being 4—5° C *cooler* than the maritime air. The southern part of the upper air trough between the two high pressure cells was extended into the equatorial easterlies. The break of the monsoon in this case was of short duration. Already on 1 August the monsoon air was back in Kabul, and the fol-

SYNOPTIC - CLIMATOLOGICAL STUDY OF THE ASIAN SUMMER MONSOON IN AFGHANISTAN

BY

TAGE R. SIVALL

Afghan Air Authority, Meteorological Department, Kabul, Afghanistan

ABSTRACT. With the help of the World Meteorological Organization (WMO), Afghanistan in 1955 started a programme of establishing a network of surface and upper air observing stations. Some of the data collected are used to study the behaviour of the Asian Summer Monsoon in eastern Afghanistan. A more detailed mean pressure chart of the monsoon heat lows over Pakistan and Afghanistan is presented, as well as an analysis of the monsoon rainfall distribution. The monsoon circulation over eastern Afghanistan and the movements of the Intertropical Front (ITF) are discussed, making use of additional unpublished data.

Introduction

Of the numerous papers dealing with monsoon problems, particularly those by Indian meteorologists, none presents a clear and generally accepted definition of the monsoon. The reason for this is quite clear. In those parts of the world where this phenomenon is of significance, local and diurnal changes of most parameters are often of a larger order than the properties of the airmasses affecting the areas concerned. To the meteorologist, the mariner and the layman, the monsoon has therefore been somewhat of a phenomenon that he experiences in his own personal way. To the mariner it is the steadiness of the wind, and to the layman, particularly in Pakistan, India and Burma it is the rainfall. However, these two elements are by no means sufficient to describe the monsoon. Therefore, most meteorologists take into account additional parameters, such as temperature, dewpoint, dewpoint depression, diurnal range of temperature and humidity, type of clouds and hydrometeors etc. Whatever parameters we use to describe the monsoon, it is a seasonal phenomenon (the word *monsoon* being derived from the Arabic word *mausim*, i.e. season).

As far as Afghanistan is concerned, the eastern parts of the country are affected by increased convective cloudiness, scattered showers—sometimes with thunder—and increased humidity from approximately the middle of June to the beginning of September. These deviations from the normal summer conditions are not associated with westerly disturbances. Instead they are associated with vortices embedded in a low-level easterly flow and can thus be said to represent the monsoon weather.

It has been argued, that the classical airmass conceptions cannot be used as a tool in forecasting the monsoon weather (Ruprecht 1970). This opinion may be due to the apparent *random character* of the weather phenomena. The monsoon precipitation generally falls as isolated showers, but this is not always the case. Furthermore, precipitation is only one of the elements of interest, and what by the meteorologist is called *monsoon* is only occasionally associated with rainfall. It is well worth noticing, that the parameters used by the meteorologists in the areas concerned are to a great extent synonymous with the parameters chosen as airmass properties in the middle latitudes.

Although some surface discontinuities are generally less pronounced than in the middle latitudes, a separation of the monsoon air from the continental air presents little problem. It can thus be argued, that the ultimate limit of the monsoon air penetration into Afghanistan should be the main target of this study, i.e. the appearance of the monsoon air over the area as obtained from statistical material. However, such statistics are of limited value, as the rainfall does not always coincide with the surface

Table 4. Weather in Kabul 29.7.—4.8. 1966, indicating break in the supply of monsoon air on 30.7. between 0900 and 1200 GMT. Compare also Fig. 28.

Date \ Time	0000	0300	0600	0900	1200	1500	1800 G.M.T
29.7.	14 / 07	23 / 13	30 / 12	33 / 14	34 / 15	29 / 14	27 / 12
		MONSOON AIR					
30.7.	15 / 08	23 / 13	30 / 15	30 / 11	33 / 02	30 / -04	27 / -04
31.7.	21 / -01	23 / -03	30 / -04	32 / -01	31 / -06	27 / -05	25 / -06
				CONTINENTAL AIR			
2.8.	20 / -00	22 / 10	27 / 08	31 / 07	32 / 02	28 / 02	23 / 02
3.8.	16 / 05	23 / 11	28 / 15	32 / 11	32 / 08	26 / 17	24 / 17
				MONSOON AIR			
4.8.	18 / 16	24 / 19	28 / 16	32 / 19	33 / 13	27 / 12	23 / 12

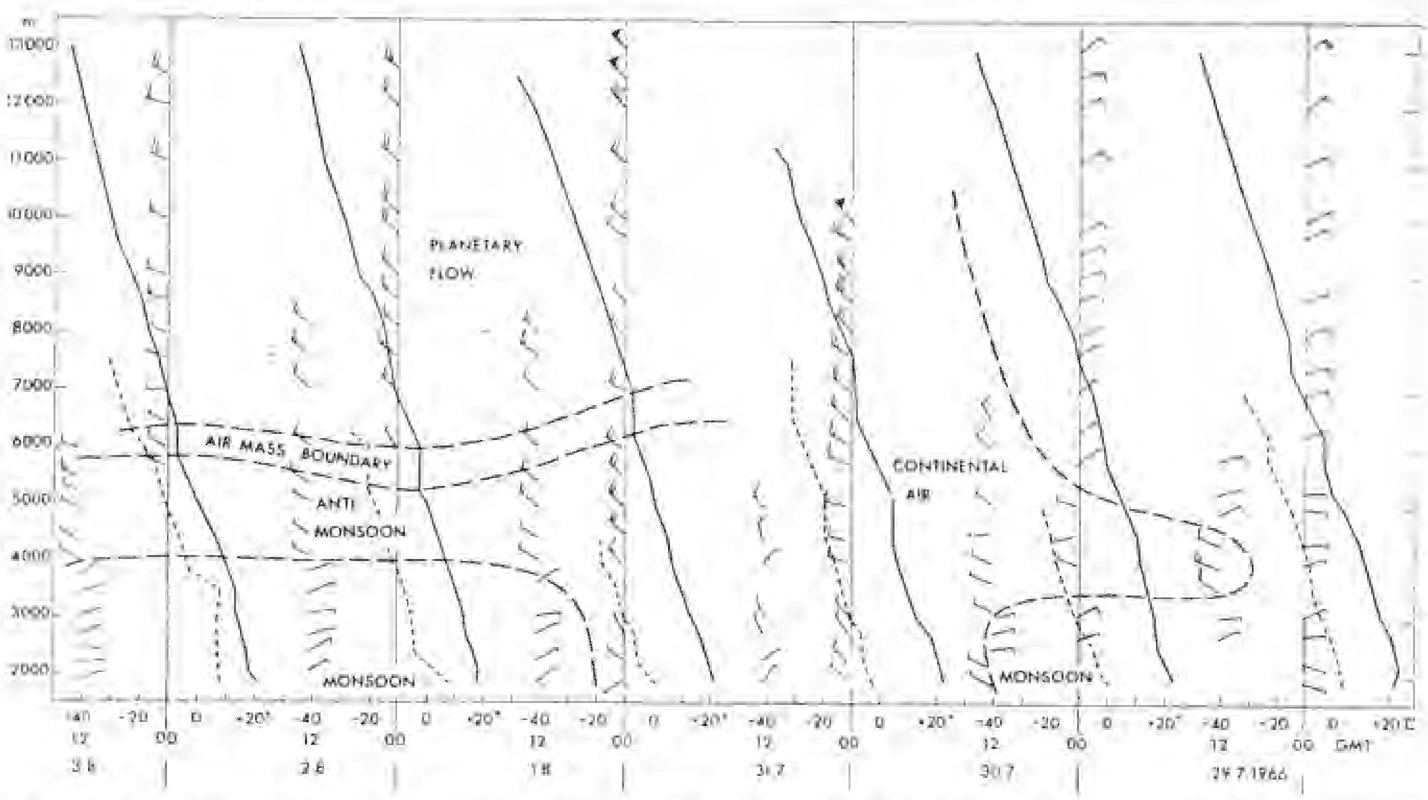


Fig. 28. Upper-air circulation and airmass stratification over Kabul at a break in the monsoon. The continental air invaded Kabul on 30 July, but it was of short duration, and on 2 August the monsoon circulation was again the streamline charts in Fig. 27 a—d).

lowing day the monsoon circulation was again fully developed (Fig. 28).

The break in the monsoon was in this case linked to the southern arm of the jetstream delta described by Weickmann Jr (1962). Although the centre of the wind maximum is not always known, the southern arm of the delta seems to reach northern Afghanistan rather seldom during the peak of the monsoon. For the years 1957—1960, 1966 and 1971 all Kabul rawind data for the months July—September have been analysed, and wind speeds 50 knots and more above 10000 m have been selected as criteria for the southern arm of the jetstream delta. Only three cases could be found in July and four cases in August. In September, however, a concentration was found towards the end of the month. In September 1971, for instance, eight cases were found, all of them concentrated to the period after 19 September. This finding seems to support the opinion of Reiter and Heuberger (1960), that there is a swift displacement of the jetstream towards its winter position south of the Himalayas as soon as the thermally produced anticyclone over Pamir and the Tibetan highland has been destroyed. Associated weather manifestations in northern Afghanistan also indicate that the process is abrupt and normally completed within a few days time in the middle or end of September. The summer monsoon in Afghanistan with its grey sky and scattered convective clouds ends with a bright blue sky and frequent cirrus uncinus.

Acknowledgement

The author is indebted to Dr. Abdul Khalek, vice President of Afghan Air Authority, with whose permission this study was carried out. Dr. N or Mohammad Herman of the Afghan Meteorological Department, and Mr. Jean Zillhardt, WMO expert to Afghanistan, have made useful suggestions and comments during the course of the work. The author also wish to thank Prof. Gösta H. Liljequist, Uppsala University, for his interest and constructive criticism.

Mr Tage Sivall, IMCOS Ltd., S Q 546, Braim, Abadan, Iran.

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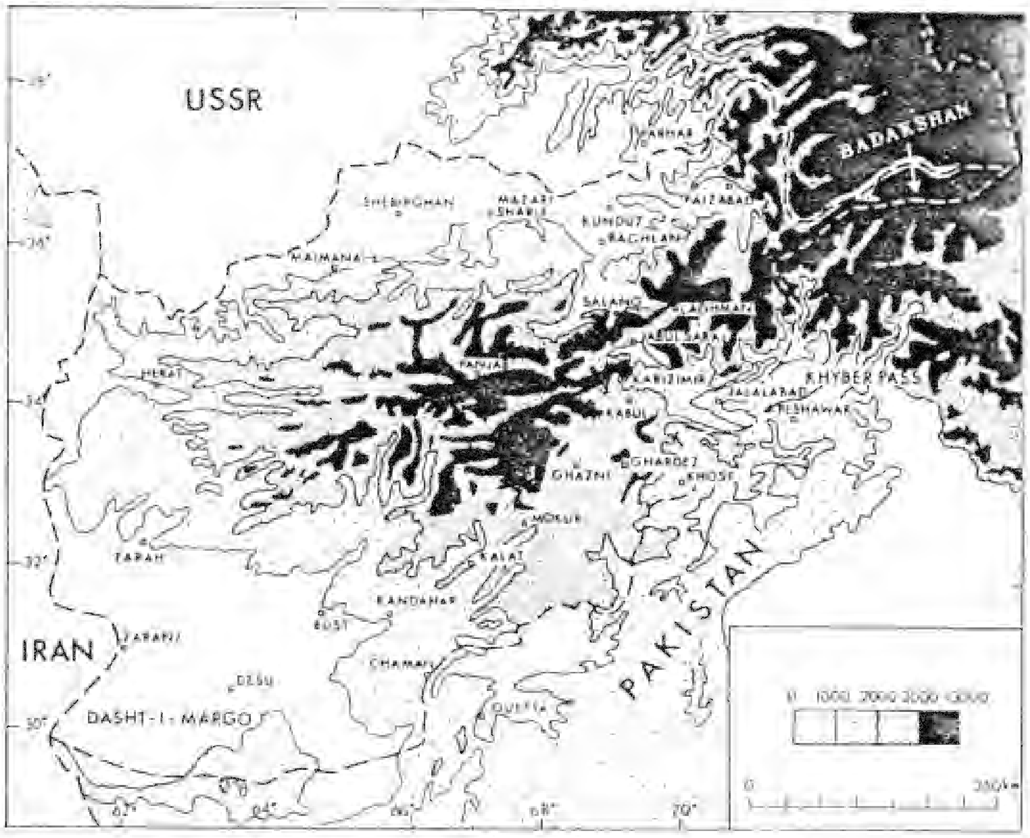


Fig. 1. Map of Afghanistan.

extension of the monsoon air. Showers can also form when the moist maritime cold air is injected at higher levels. The surface data should thus be consulted with utmost discretion and if possible only in combination with upper air data. The problem is similar to that facing the forecaster in middle latitudes in summer. In both cases it is a question of forecasting the airmass weather, taking into account also the stratification of the airmasses. These principles have been applied for several years and with reasonable success by the Afghan Meteorological Department.

Owing to the lack of a clear definition and in order to avoid any misunderstanding, the expression *monsoon* will in this study be used only to describe a particular link in the circulation mechanism, thereby bringing the expression more in harmony with its original meaning. More specifically, the study will deal with the circulation and the behaviour of the airmasses affecting the area under review and their weather manifestations during the summer months. In that connection the expression *monsoon air* will sometimes be used instead of the synoptically more adequate expression *maritime equatorial air*.

Geographical features

Afghanistan is situated between latitude 29° N and 37° N, and longitude 61° E and 72° E (Fig. 1). It is a very mountainous country and its weather and climate are therefore to a great extent influenced by the topography. Generally speaking the country is divided into two parts by the Hindu Kush mountains; the northern plain bordering on the USSR, and the desert in the south bordering on Pakistan. The Hindu Kush mountain range is a continuation of the Himalayas and runs from Badakshan in the northeast towards the Iranian border at Herat and Farah in the southwest. From Badakshan, where the highest peaks are about 6500—7000 m, the mountain range slopes down to 1500—2000 m in the neighbourhood of Herat. The elevation of the northern plain is between 250 and 400 m, whereas the desert south of Hindu Kush slopes from about 1200 m in the east to 500—600 m in the west. The western desert bordering to Iran is to a great extent occupied by salt lakes and swamps fed by the Helmand river.

In central Afghanistan the mountain range is very wide and occupies 300—400 km in a north-south direction. Eastwards it becomes

narrower and north of Kabul it is only 40—60 km wide over the Salang pass. Further eastwards it widens again.

Along the longitude through Kabul the country is also divided into two parts. A valley runs roughly from Kandahar in the south, through Kalat, Mukur, Ghazni and Kabul to Jabul Saraj situated at the foot of the mountain range just south of the Salang pass. North of Salang the valley continues and ends in the northern plain at Baghlan and Kunduz.

Another valley of importance runs along the Kabul river from Kabul in the west through Jalalabad to the Pakistan border north of the Khyber pass.

Finally, there is a mountain range of importance running along the Afghan-Pakistan border from Jalalabad in the north through Khost to Chaman in the south. Its highest peaks of about 4700 m are situated just south of Jalalabad and from there the range slopes down to about 2300 m at Chaman.

Network and data

Bearing in mind the topography of the country, the network of meteorological observing stations in Afghanistan is still too sparse to permit a more detailed description of the climate (Stenz 1946, Herman et.al. 1971, Herman 1965). Furthermore as most stations have been established during the last few years, and in some cases the location has been changed. Some records go back to the beginning of 1940, but those data are of limited value as in a great many cases such essential information as date and location are missing. Furthermore, Afghan Standard Time which is GMT $+4\frac{1}{2}$ hours was officially first introduced in March 1956.

There are in some cases serious gaps in the records of surface observations. For synoptic studies the few and sometimes sporadic upper air observations present an even more serious obstacle. Radiosonde/wind data or sometimes pibal observations have been made at Kabul since 1959, but there are gaps in the records of up to several months. From Mazari Sharif, Kandahar and Jalalabad short pibal records are also available. Some of the stations have been established by the author, who has also inspected all Afghan stations several times. Thus stations considered less representative from a synoptic point of view have been excluded in this study. The elevation of most

Table 1. Selected network of Afghan meteorological observing stations used in this study, and the year of establishment.

Station	Index number	Latitude	Longitude	Elevation	Established
Baghlan	40 914	36° 12′ N	68° 45′ E	510 m	1958
Bust	988	31° 33′	64° 22′	780	1960
Faizabad	904	37° 07′	70° 31′	1200	1963
Farah	974	32° 21′	62° 09′	660	1960
Ghardez	970	33° 37′	69° 14′	2350	1964
Ghazni	968	33° 32′	68° 25′	2183	1957
Herat	938	34° 13′	62° 13′	964	1958
Jabul Saraj	932	35° 08′	69° 15′	1630	1961
Jalalabad	954	34° 26′	70° 28′	580	1958
Kabul	948	34° 33′	69° 13′	1791	1956
Kalat	979	32° 07′	66° 54′	1565	1967
Kandahar	990	31° 30′	65° 51′	1010	1963
Karizimir	949	34° 38′	69° 03′	1905	1958
Khost	971	33° 21′	69° 57′	1146	1962
Kunduz	913	36° 40′	68° 55′	433	1964
Laghman	952	34° 39′	70° 13′	770	1965
Maimana	922	35° 55′	64° 45′	815	1958
Mazari Sharif	911	36° 42′	67° 12′	378	1957
Mokur	980	32° 50′	67° 47′	2000	1966
Panjab	946	34° 23′	67° 02′	2710	1965
South Salang	931	35° 18′	69° 04′	3172	1962
Shebirghan	908	36° 40′	65° 43′	360	1963
Zaranj	986	31° 00′	61° 51′	478	1969



Fig. 3 a. Sand dunes at Desu, situated in the desert about 150 km southwest of Bust. The orientation of the dunes indicates the prevailing wind direction.

stations has been revised, using the latest available data supplied by the Afghan Institute of Cartography. The pressure data have been recalculated using the same formulae as the USSR and Pakistan according to the WMO Technical Note No. 91. Under the above conditions a geostrophic balance has been assumed by analysing the charts.

The Pakistan upper air observations from Peshawar and Quetta, situated close to the Afghan-Pakistan border, have been of particular interest. Unfortunately there are, however, large gaps also in these records.

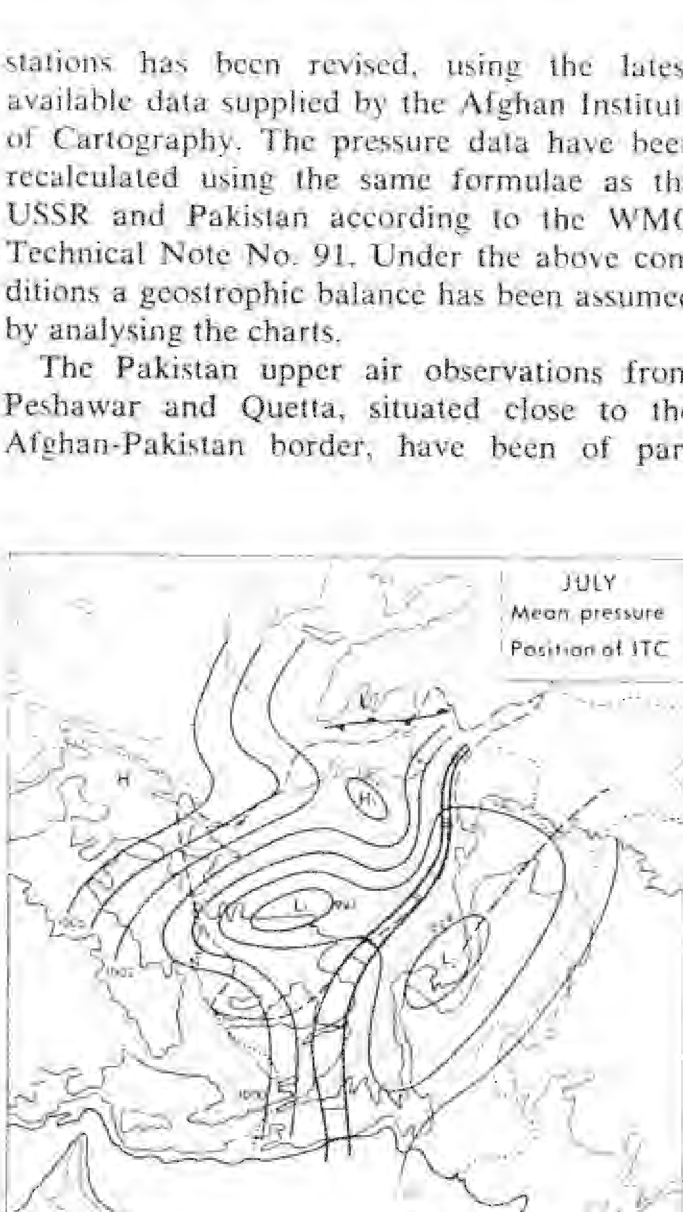


Fig. 2. Mean pressure distribution over Afghanistan and adjacent areas in July. The average position of the ITF (ITC) is drawn between the two heat lows L_1 and L_2.

Climatological features

In most textbooks the Asian Summer Monsoon circulation is attributed to the seasonal warming of the air over Saudi Arabia and the Indian Subcontinent that results in the formation of a system of heat lows. Whereas June can be said to represent the pre-monsoon month, the circulation is fully developed in July and August. At the beginning of September the monsoon normally begins to retreat.

The main heat lows referred to are situated

1. over the central portions of the Persian Gulf,
2. over southern Pakistan, with the centre at about 28° N, 69° E.

Of these two centres only that over Pakistan will be dealt with in this study. Using new data from Afghanistan, a more detailed surface mean pressure chart for July is presented in Fig. 2. In drawing the isobars, wind-roses from a number of selected stations have



Fig. 3 b. Formation of sand dunes due to the lee eddy.

been used as well as other manifestations of the prevailing winds.

The new pressure data from Farah and Zaranj in the south-western corner of Afghanistan as well as the prevailing winds from these stations, plus those from Bust, Kandahar and Kalat in the south-east clearly indicate, that we have to take into account two heat low cells, of which the main heat low L_1 is situated over the desert Dasht-I-Margo in southern Afghanistan. The photograph of the 10—15 m high sand dunes in Fig. 3 a was taken from Desu about 150 km southwest of Bust. The orientation of the dunes indicates prevailing winds between west and northwest, which is in accordance with the position of L_1. The heat low pressure cell L_2 over Pakistan must no doubt be considered as a secondary heat low.

The northerly low pressure cell L_3 can only to some extent be classified a heat low. It is situated just south of the Hindu Kush mountains and must be regarded mainly as a lee depression, formed as a result of the persistent upper air northwesterly current. The appearance of a high pressure cell H_1 on the windward side of the mountain range seems to confirm this opinion (Herman 1965).

Wind roses for several Afghan stations have been constructed for the month of July, using data from up to 10 years. Those for the stations in eastern Afghanistan appear on Fig. 4. There are principally two types of wind roses; those indicating *two* dominating wind directions and those indicating only *one* dominating wind direction. Examples of the first type are given by some stations south and southwest of Kabul. Thus Kalat and Mukur have the wind frequencies from NE and SW about equally distributed. The wind in Ghazni is mainly from N, but there is also an appreciable frequency from S. Similarly in Ghardez, situated just east of Ghazni, the main wind is from NNE, but with a rather high frequency also from SW. It is important to notice that all these stations are situated between the two heat lows L_1 and L_2. The wind roses from the remaining stations belong to the second type. Kabul and the stations north of it have winds between N and NE, whereas the stations east of Kabul have mainly easterly winds. In Kandahar, situated in the south, the winds between SW and W dominate. On the mean pressure chart for July in Fig. 5 stations of the first type have been plotted with two arrows in the directions of the prevailing winds, and stations of the second type have been plotted with one arrow only.

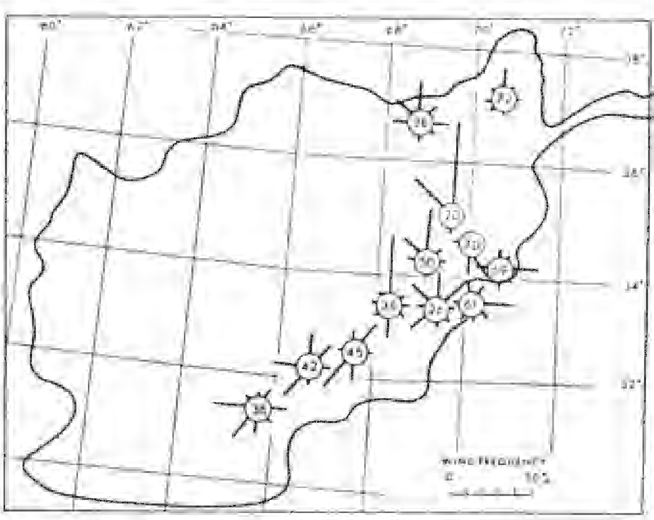


Fig. 4. Wind roses for the month of July from a number of Afghan stations. The numbers in the circles are the percentages of calm.

Airmasses

The airmasses involved in the low-level circulation can be derived directly from the pres-



Fig. 5. Mean sea level pressure for July for a number of selected stations in Afghanistan, Pakistan and the USSR. The arrows indicate the prevailing winds during the month. Some stations have two arrows, indicating two prevailing wind directions (compare Fig. 4).

sure distribution. Thus we have a mainly northerly or northwesterly current of warm and dry continental air over the northeastern part of Afghanistan. Over the western parts of the country the flow is between N and NE. This is the well known *Shamal* in Iran, which in western Afghanistan is called *jak sad bist rooz,* meaning 120 days. The period corresponds well to the length of the monsoon season (Sivall 1962).

Over the southern parts of Pakistan we have a mainly southwesterly current of maritime equatorial air; the so called Asian or Indian Summer monsoon. One branch of that current converges into L_2, whereas the second branch flows towards the northeast. South of the Himalayas this second branch is deflected by the topography and reaches L_3 as an easterly or sometimes northeasterly current. As to the persistance of L_2 different opinions have been expressed. According to Ramage (1966) it is related to the subsidence over it, and this subsidence "limits the height to which surface air from the Arabian Sea can ascend, restricting cloud development and thus favouring strong insolational heating". Desai (1967) on the other hand is of the opinion that the inversion over L_2 is an airmass boundary and not the result of subsidence. He refers to the marked increase in temperature from south to north in the upper troposphere. That fact has been verified by Flohn (1966), who has pointed out that the equatorial air above 8° N is about 8—11° C cooler than the subtropical air above the heat low L_2. However, he has also made the remark that the reversed horizontal temperature gradient is not necessarily related to an airmass boundary. The summer heat source over the Tibetan highlands as well as the release of latent heat from the heavy rains in Bangladesh and Burma contribute according to Flohn to the reversed horizontal temperature gradient. Ramage's interpretation is also supported by Flohn et al (1968), who attribute the inversion mainly to the divergence in the southwest monsoon current mentioned above. As far as the Thar desert in the southern part of L_2 is concerned, the opinion has later been verified by Ruprecht (1970).

The differences between the two heat lows L_2 and L_1 as well as the similarities are of great significance. L_2 is occupied by a shallow layer of cool maritime air, whereas L_1 is occupied by relatively warm continental air probably up to great heights. Thus clouds are rare and precipitation nonexistant in L_1 because of the extreme dryness of the air. The basic condition for its existence is consequently fulfilled and for the maintenance of that heat low the question of subsidence or no subsidence is of little interest. This is not so with L_2, for whose existence the inversion is of basic importance. Under the influence of an approaching monsoon disturbance the moist layer becomes thicker, thus permitting cloud formation and occasionally precipitation. These factors obviously reduce the insolational heating. It is therefore fair to state that in the mean pressure distribution L_2 is not to be considered as the main heat low. Conditions in the northerly low pressure cell L_3 will be discussed separately in next chapter.

Concerning the separation of the continental and the maritime airmasses by a front or a convergence zone, Soliman (1958) has pointed out that the ITF (ITC) cannot be located in the centre of a heat low because it consists of a single hot airmass surrounded by cooler air. L_2 is without any doubt a heat low and the convergence zone through it is consequently not identical with the ITF (ITC).

The position of the airmass boundary between L_1 and L_2, as illustrated in Fig. 2, is based upon a careful examination of wind, temperature and humidity as well as of precipitation. The northern part is drawn through L_3, which is mainly of dynamic origin. The discontinuities of wind and humidity are very pronounced. In a great many cases also a certain temperature discontinuity can be observed. The dryness of the northwesterly current can to a certain extent be attributed to the katabatic character of the wind, but it is certainly not the main reason as the airmass is of continental origin. South of latitude 31° N the boundary becomes less pronounced as it passes through the divergence zone between L_1 and L_2.

The boundary in this study is called the ITF more for the sake of convenience, thereby at least to some extent following the classical definition of a surface front as expressed by Bergeron (Dyn. Met. 1957), although the expression *zone* might be more relevant south of 31° N. The author is also aware of the fact that the slope of the airmass boundary in this

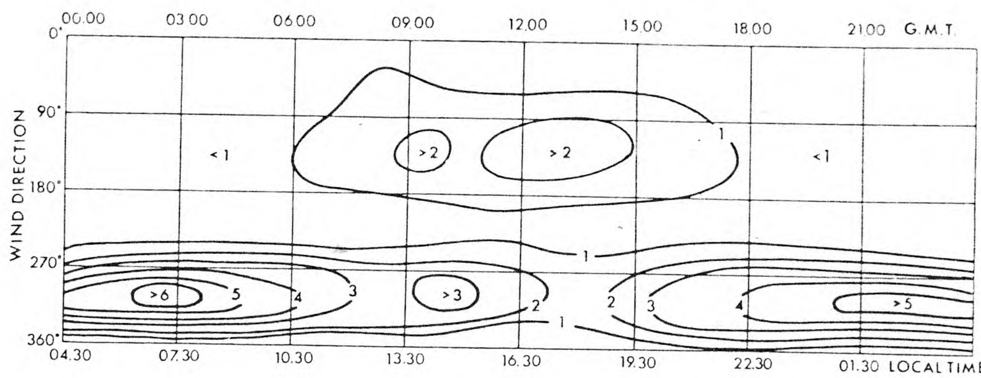


Fig. 6. Diurnal variation in July of wind direction in Ghazni. The dominating wind is from northwest, but at noon there is an appreciable frequency also from south.

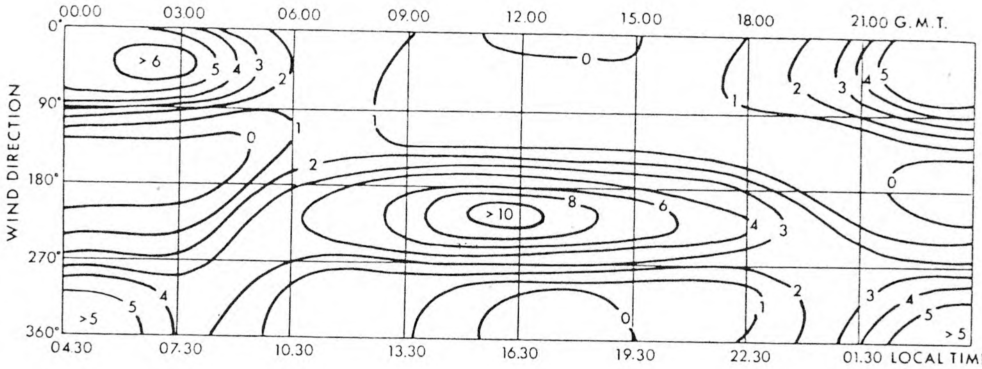


Fig. 7. Diurnal variation of wind direction in Mukur during July. The northerly winds dominate at night. In daytime the winds are mainly between SE and SW.

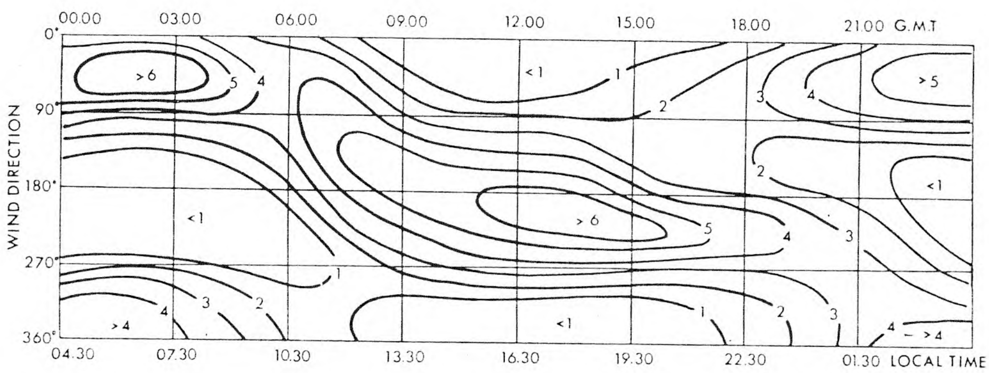


Fig. 8. Diurnal variation of wind direction in Kalat during July. Northerly winds dominate at night. In daytime the winds are generally from SW.

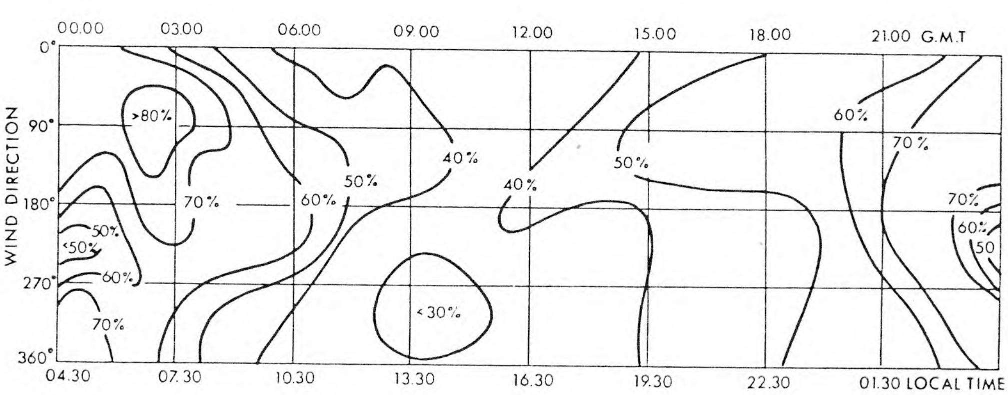


Fig. 9. Diurnal variation of relative humidity in relation to wind direction at Ghazni during July. With winds between SE and NE the relative humidity is generally higher than with any other wind direction.

case seldom corresponds to that of a middle latitude front.

The isograms in Fig. 6, 7 and 8 illustrate the diurnal variation of the wind direction at the three border stations Ghazni, Mukur and Kalat taken in order from north to south. The distance between them is 60—70 km. Starting with the northernmost station in Ghazni, the dominating wind direction is from northwest. At noon, however, the frequency of southeasterly winds increases. In Mukur the difference between day and night is more pronounced with northerly winds dominating at night. In the daytime there is a change to SE or even SW. In Kalat, finally, the difference between day and night is very distinct. The northeasterly winds at night are clearly separated from the southwesterly winds at daytime. The changes in Mukur and Kalat take place at about 10 and 21 o'clock local time. Mountain and valley wind systems no doubt play an important role, but it is certainly not the sole reason for the wind shifts. Thus, there is for instance in Ghazni also a relationship between wind direction and humidity. The shape of the isopleths in Fig. 9 illustrates that the drop in relative humidity at the time of maximum temperature is less with winds between SE and NE than with winds from any other direction. In Ghardez and Khost, situated east of Ghazni, the correlation between wind direction and humidity seems to be still more pronounced. The wind shifts are thus no doubt also related to the diurnal oscillation of the ITF, which in turn can be referred back to the diurnal changes in pressure similar to that reported from several places in Africa and Asia. The periodic and non-periodic movements of the ITF will be subject to a more detailed investigation later in this study. However, based upon our present knowledge of the wind and humidity conditions, the average position of the ITF in July seems to be just over Ghardez. It seems to affect Mukur and Kalat less frequently and has therefore been drawn east of these stations.

A diurnal variation of the wind direction is also observed at several stations in southern USSR bordering Afghanistan, but the phenomenon has nothing to do with the ITF. It is one of the areas where Soliman locates the so called Subtropical Front (STF) in summertime (Soliman, 1958 p. 137, Fig. 1 and 2). However, it is well known that the Pamir mountains form an effective barrier for the middle latitude disturbances arriving from the west (Bugaev et.al. 1962). The area is thus frequently occupied by the "trailing ends of meridional cold fronts in the westerlies", as pointed out in a remark by Hanney (1962), but also mountain and valley wind systems must play an important role here.

Precipitation

We now turn our attention to the precipitation over the area under review. In this study the rainfall during June, July and August is attributed to monsoon influences, but only under the condition that the annual distribution of precipitation is characterized by a secondary maximum during those months. Thus Ghazni for instance is considered to be influenced by

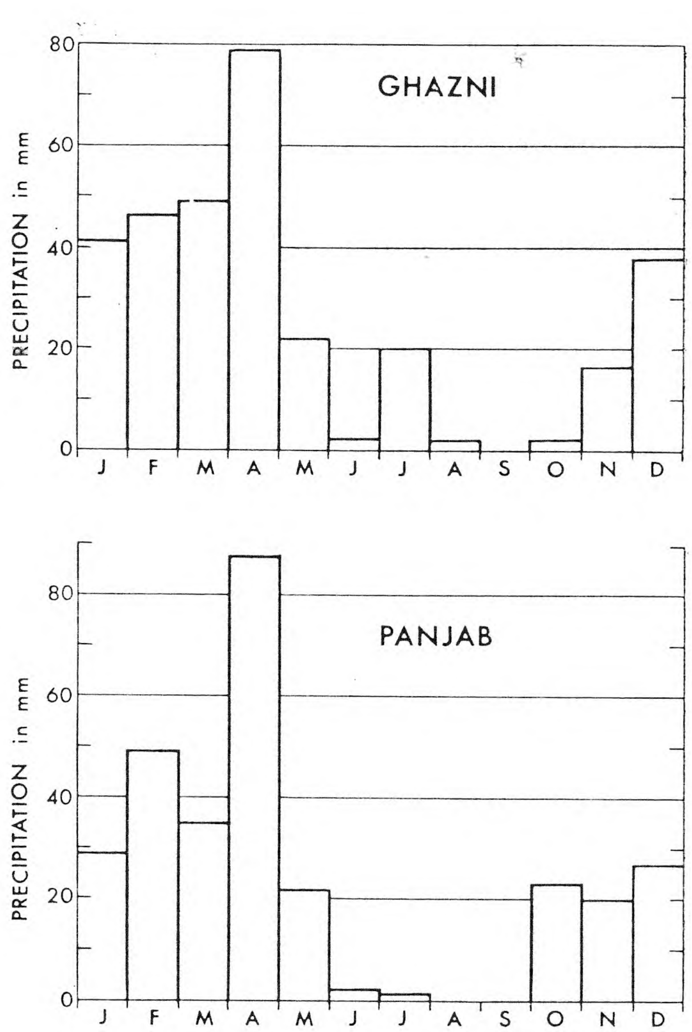


Fig. 10. Monthly mean precipitation in Ghazni and Panjab. Ghazni has a secondary maximum in July, and is thus considered to be influenced by the monsoon. Panjab has no such secondary maximum in summertime, and is therefore not considered to be influenced by the monsoon.

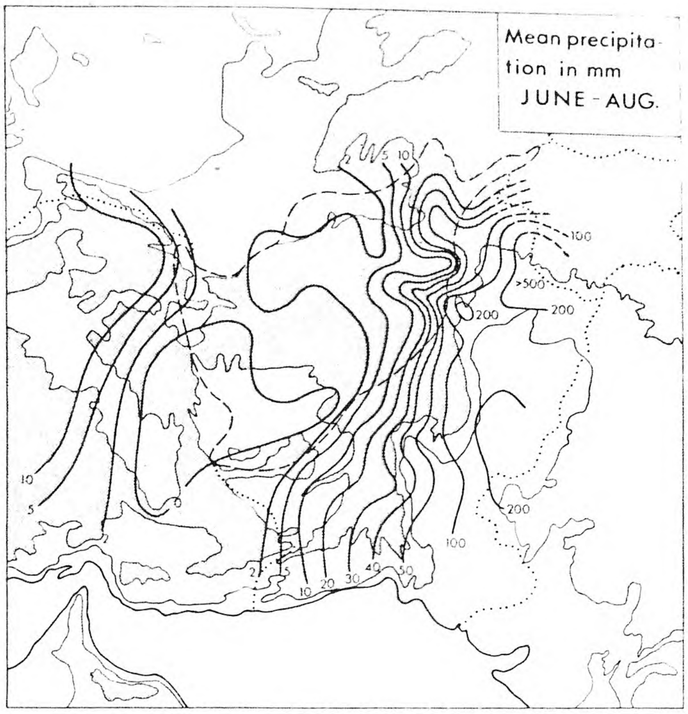


Fig. 11. Mean sum of precipitation for the months of June, July and August in Afghanistan and adjacent areas. Only in Pakistan and eastern Afghanistan is the rainfall due to monsoon influence. Notice the shape of the 10 mm isohyet along the Kabul river between Kabul and Jalalabad.

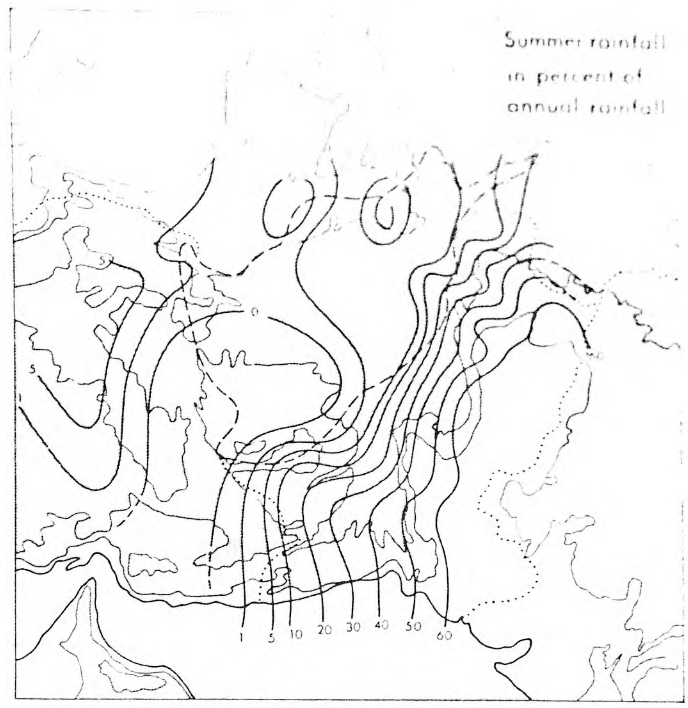


Fig. 12. Monsoon rainfall in Afghanistan and adjacent areas as a percentage of the total annual rainfall. The 10 % isomer runs pratically along the ITF and the Afghan-Pakistan border.

the monsoon, but not Panjab situated further west (Fig. 10).

The mean sum of precipitation for the months June, July and August is illustrated in Fig. 11. Afghanistan is situated between three main rainfall regions. The most important one is situated over Pakistan, a second one over the Pamir, and a third over Iran. Over Afghanistan itself appreciable summer precipitation falls only along the eastern border. Small amounts are also reported in the Hindu Kush mountains west of Kabul and at some places in the plain north of Hindu Kush. Otherwise summer precipitation is very rare. The influence of topography is considerable as can be seen for instance in the shape of the 10 mm isohyet, which closely follows the valley along the Kabul river from Kabul to Jalalabad, with the smallest amount of precipitation in the valley.

In Iran and southern USSR the records do not show any secondary maximum in summertime. These areas are consequently not considered to be influenced by the monsoon.

The summer precipitation given as a percentage of the annual precipitation is illustrated in Fig. 12. In most parts of Pakistan the monsoon rain contributes to more than 50 % of the total annual rainfall. It decreases rapidly westwards and the 10 % isomer runs practically parallel with the ITF and the Afghan-Pakistan border. From the maximum at about 32° N it also decreases northwards as well as towards

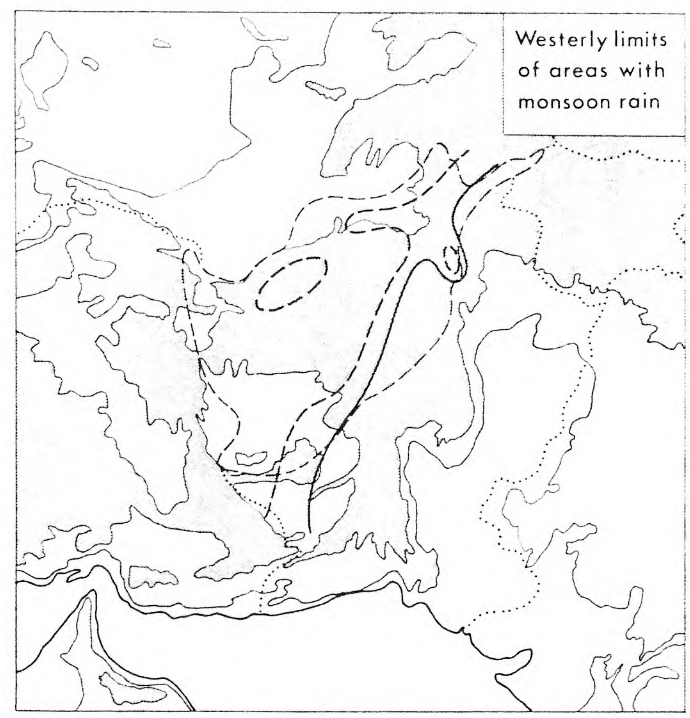


Fig. 13. Boundaries between areas regularly influenced by monsoon rainfall ————, and areas occasionally influenced by monsoon rainfall — — — — —. Notice the areas occasionally influenced around Jalalabad and in the mountains north and west of Kabul.